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Field Evaluation of the SIMSLIN II Light Scattering Instantaneous Dust Monitor

U.S. Department of Labor
Mine Safety and Health Administration

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U.S. Department of Labor
Raymond J. Donovan, Secretary

Mine Safety and Health Administration
David A. Zegeer, Assistant Secretary
1984

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FIELD EVALUATION OF THE SIMSLIN II LIGHT-SCATTERING INSTANTANEOUS DUST MONITOR

By Andrew J. Gero,[1] A. J. Beckert,[2] Robert A. Jankowski,[3] and Thomas F. Tomb[4]

ABSTRACT

This paper presents and discusses the results of measurements made in underground coal mines with the SIMSLIN II respirable dust monitor. The SIMSLIN II is an instantaneous-reading dust monitor employing the principle of light-scattering to measure the mass concentration of respirable dust. The instrument was designed and developed by the Safety in Mines Research Establishment in the United Kingdom. During this evaluation, full-shift gravimetric respirable mass measurements were compared with integrated signals obtained from the scattered-light detector. Comparative measurements were obtained on coal mine dust clouds varying in particle size distribution, composition, and concentration to evaluate their effects on instrument calibration. In addition, tests were conducted to evaluate the instrument's potential use as a machine-mounted respirable dust monitor capable of providing real-time information to a continuous mining machine operator.

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INTRODUCTION

Control of dust levels in coal mines for the purpose of preventing coal workers' pneumoconiosis is periodically monitored through full-shift measurements with apparatus consisting of an elutriator, a filter cassette, and a small pump. The filter is mailed to a central laboratory for weighing, with the result then returned to the mine operator. This system has a number of disadvantages, among which are the following:

1. The dust concentration is not known until after the fact, so no immediate corrective action can be taken to ameliorate high dust levels;

2. Continuous compliance with applicable dust standards is only assured during periods of sampling for compliance determinations.

In order to improve the system, a research program was implemented to develop a machine-mounted respirable dust monitor (MMRDM), a device which is rugged enough to be mounted on mining equipment and continuously monitors, displays, and records the dust level in its immediate environment. Such a device would indicate to the machine operator the need for corrective action and the effectiveness of such action. It would also allow the determination of average dust concentration without the need to send a sample to a central laboratory for analysis.

Three principles having the potential for use in continuous monitoring of dust levels are light-scattering, beta-ray attenuation, and change in resonant frequency of a piezoelectric quartz crystal. The need to clean the crystal after only a very small amount of dust has been deposited and the relatively high dust concentrations found in coal mines have deterred development of an instrument using the piezoelectric crystal principle for in-mine use.

A number of instruments using beta-ray attenuation are commercially available. These instruments do not continuously monitor airborne dust concentration, but deposit dust on a substrate for a period of time and determine the mass of dust deposited during this period by measuring the change in beta-ray attenuation. The length of time required for dust deposition is somewhat dependent on dust concentration, as there are minimum and maximum amounts of deposited dust required for accurate measurement.[5] A clean substrate is needed for each measurement, requiring a complex mechanical apparatus for automated operation. Application of the principle of beta-ray attenuation for the development of a machine-mounted respirable dust monitor has been investigated under U.S. Bureau of Mines research contracts.[6]

Instruments using the principle of light-scattering do not require that the dust be deposited but measure the concentration as the dust passes through a light beam, thus allowing greater mechanical simplicity and more rapid measurement. However, unlike instruments utilizing the other two principles, the response from the light-scattering instruments is not a direct function of particulate mass. The response may be affected by such factors as particle size distribution and composition (refractive index).[7] Appropriate selection of light wavelength and scattering angle can minimize these effects.

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[5]GCA Corporation. Instruction Manual: Respirable Dust Monitor Model RDM-301. Bedford, Massachusetts, 1976, 48 pp.

[6]U.S. Bureau of Mines Contract H0166097, GCA Corporation. Machine-Mounted Respirable Dust Monitor. Bedford, Massachusetts, 12 pp.

U.S. Bureau of Mines Contract H0166186, Bendix Corporation. Machine-Mounted Respirable Dust Monitor. Baltimore, Maryland, 10 pp.

[7]Hodkinson, J. R. The Optical Measurement of Aerosols. Aerosol Science, ed. by C. N. Davies, 1966, pp. 287-357.

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At least three instruments using light-scattering to measure the mass concentration of dust are commercially available. Although none of these was specifically designed for use as a machine-mounted dust monitor, they have the potential of being modified to fulfill such a purpose. This report describes tests performed in underground coal mines with one of these instruments, the SIMSLIN II respirable dust monitor. The purpose of the tests was to establish the feasibility of the light-scattering technique for measuring dust concentrations in underground environments and to determine its ability to withstand the conditions to which it is exposed when mounted on a mining machine.

CHARACTERISTICS OF SIMSLIN II

SIMSLIN II,[8] developed by the Safety in Mines Research Establishment in the United Kingdom, uses a pulsed diode laser radiation source with a wavelength of 0.904 micrometer and measures radiation scattered between 12 and 20 degrees; the near-forward scattering angle was chosen to minimize the effect of differing refractive indices of different materials. The respirable fraction of dust, as defined by the British Medical Research Council[9] penetration curve, is separated with a flat-plate elutriator at a flow rate of 0.625 liters per minute. After passing through the light beam, the dust is collected on a removable filter which is gravimetrically analyzed to determine the concentration. The design of the elutriator and choice of the flow rate are such that the dust concentration found from the filter weight should be the same as that found with the MRE Type 113A gravimetric dust sampler. A laboratory investigation[10] confirmed that mass concentration determinations obtained with both instruments are equivalent.

The electrical signal from the light-scattering system is processed by low-power electronics to give analog and digital readings which are proportional to the dust concentration. The instantaneous reading is displayed on a liquid crystal display. There are two ranges, 0 to 20 mg/m^3 and 0 to 200 mg/m^3. A digital averager circuit calculates the cumulative average dust concentration. The cumulative average is updated every 15 minutes and displayed on demand. The analog and digital signal readings are accessible for driving auxiliary instrumentation.

Since the light-scattering system in the SIMSLIN II has no absolute calibration in terms of the gravimetric dust concentration, an empirical calibration is obtained by adjusting the electrical sensitivity of the instrument until the cumulative average from the light-scattering system agrees with the gravimetrically determined concentration.

PROCEDURES

To determine the effect of different coal mine aerosols on the response of the SIMSLIN II, six instruments, after calibration with -200 mesh Pittsburgh Seam coal dust in a laboratory dust chamber, were exposed to a variety of mine environments. All in-mine measurements were made by personnel from MSHA's Coal Mine

[8]Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Mine Safety and Health Administration.

[9]Orenstein, A. J., et al. Proceedings of the Pneumoconiosis Conference, Johannesburg, South Africa, Feb. 9 to 24, 1959. J. and A. Churchill, Ltd., London, England, 1960, p. 619.

[10]Thompson, E. M., et al. Laboratory Evaluation of Instantaneous Reading Dust Monitors. Presented at the American Industrial Hygiene Conference, Houston, Texas, May 19 to 23, 1980.

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Safety and Health inspection force, after receiving a thorough training course on instrument operation. Approximately 25 full-shift measurements (not including mantrip time) were made with each instrument. The measurements were made either in the immediate return off a working place or at a transfer or dump point. All measurements were made using the 0- to 200-mg/m^3 range. A total of 146 such measurements were obtained in 65 different mines. For each measurement, the averager reading at the end of the shift was compared with the concentration determined from the filter weight and sampling time. Filters were pre- and post-weighed at a central laboratory to ±0.01 mg. In addition, the instrument's instantaneous readout was observed for a sufficient period to determine the maximum concentration measured at the sampling location.

Tests of a machine-mounted respirable dust monitor were conducted using SIMSLIN II as the dust-measuring unit. The objectives of these tests were to investigate the usefulness of the MMRDM concept and the suitability of SIMSLIN II for use in such a device. The relationship between mass concentration measurements determined from the electronic response of the instrument and gravimetrically from the dust deposited on the internal filter was also evaluated.

The SIMSLIN II was enclosed in a vibration-resistant box and mounted on a continuous mining machine inby (toward the source of dust) the machine operator's position. The instrument's analog signal was coupled to an electronic box that had the capability to activate green, yellow or red lights, depending on the dust concentration. The green light activated at concentrations up to 2.5 mg/m^3, the yellow at concentrations between 2.5 and 10.0 mg/m^3, and the red at concentrations above 10.0 mg/m^3. The unit also had an integrating circuit that provided the cumulative average concentration at any point in time and a circuit to flash a red alert light whenever the cumulative full-shift concentration exceeded 2.5 mg/m^3.

The MMRDM was tested in three mines over a total of 37 shifts. Prior to testing in each mine the instrument was operated for two shifts in the mine to check out the equipment and procedures. If the relative response of the light-scattering system was similar for both shifts, SIMSLIN II was calibrated on the basis of the results from one of these measurements. Unlike the tests performed by inspection personnel, who had other duties, the MMRDM tests were continuously monitored. Although each test was conducted within one mine, it was sometimes necessary to sample in a different section or to use a different SIMSLIN II during the test. As in the other tests, the averager reading was compared to the concentration determined from the filter weight; in these tests the cumulative concentration from the electronic box was also compared to the SIMSLIM II's averager reading.

TREATMENT OF DATA

The calibration procedure, being based on two points (0 and one gravimetric concentration) assumes a linear relationship between the gravimetric concentration and that found by the light-scattering system. Therefore, the method of least squares was used to obtain the best estimate of the regression line relating the averager reading to the concentration found from the filter weight. The correlation coefficient (r) and standard error of estimate ($S_{y/x}$) were also calculated for each regression line. The standard error of estimate was used to evaluate the relative degree of spread about the various regression lines and the correlation coefficient used as a measure of the degree of linearity between the two variables. The parameters defining the regression lines were compared to determine calibration variability and the standard errors of estimate compared to determine

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the gross effects of aerosol size distribution and composition on instrument response.

Respirable dust measurements, based on the gravimetric determination, greater than 11 mg/m^3 were not included in calculation of the regression equation, as they are outside the range of interest for the intended application of the machine-mounted respirable dust monitor. All other data were included, although it could be inferred from the dust pattern on the filter that some might be questionable because of possible leaks or backward insertion of the filter holder, and because some filters had been torn slightly in handling. These data were not excluded because it was uncertain whether the suspected operational errors had in fact occurred, or whether they had any significant effect.

RESULTS AND DISCUSSION

The least-squares regression lines relating averager reading to gravimetric concentration for measurements obtained by inspection personnel are shown as the solid lines in figures 1 through 6. The equation for the regression line, the correlation coefficient, and the standard error of estimate for the respective instruments are shown on the appropriate figure. The dashed line indicates a hypothetical one-to-one correspondence. Figures 7 through 9 depict the same information for the MMRDM tests.

Comparison of the various regression lines for data collected by inspection personnel indicates that there was a high degree of variability in the calibration

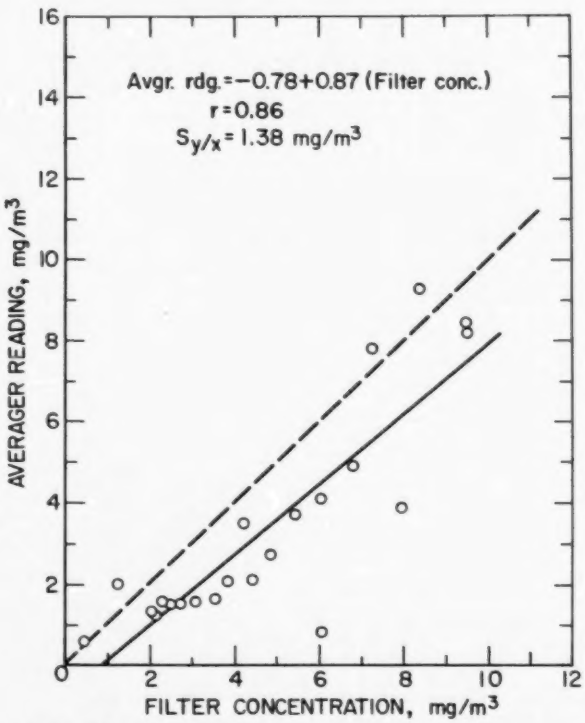

FIGURE 1. - Comparison of respirable dust concentrations found with the light-scattering system to those found from filter weights–SIMSLIN No. 128–District 5.

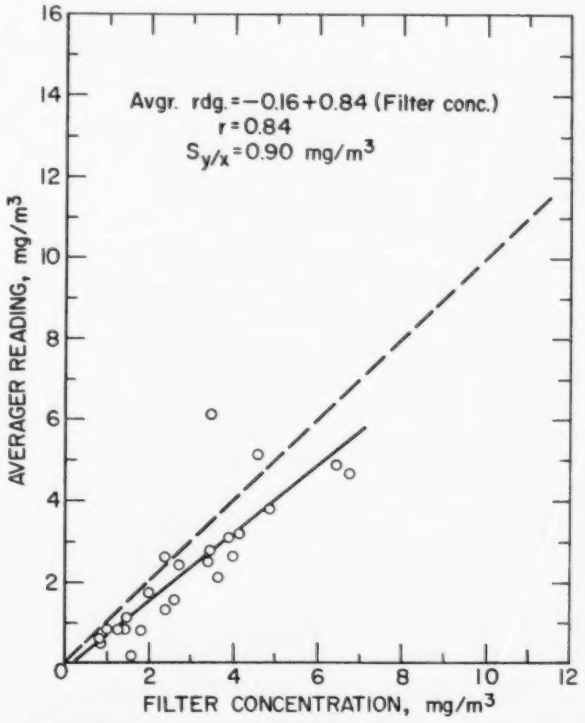

FIGURE 2. - Comparison of respirable dust concentrations found with the light-scattering system to those found from filter weights–SIMSLIN No. 130–District 9.

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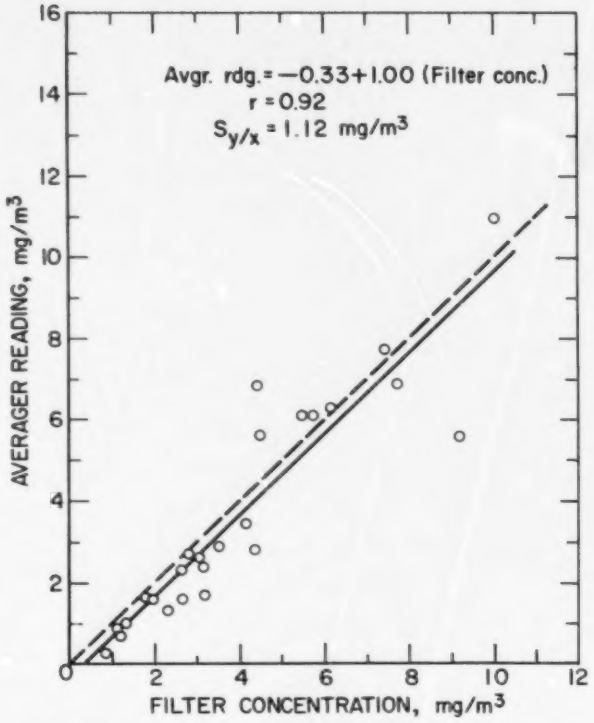

FIGURE 3. - Comparison of respirable dust concentrations found with the light-scattering system to those found from filter weights–SIMSLIN No. 131–District 4.

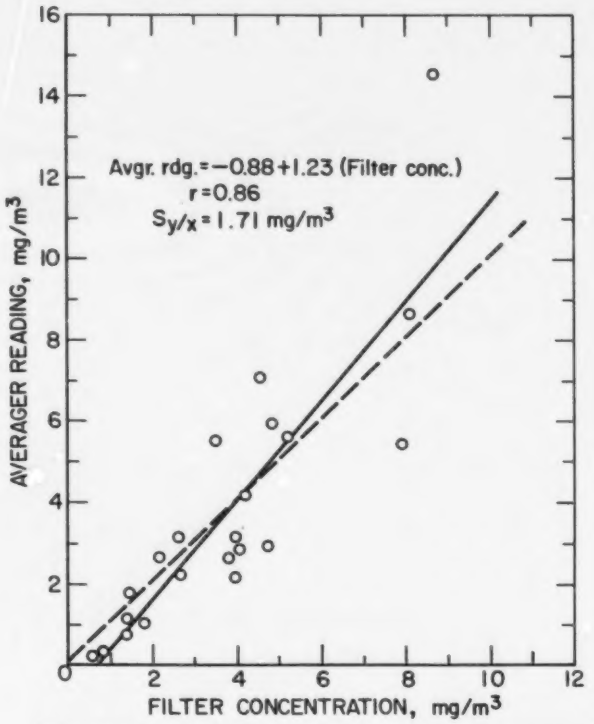

FIGURE 4. - Comparison of respirable dust concentrations found with the light-scattering system to those found from filter weights–SIMSLIN No. 132–District 9.

of the instruments. This is evidenced by the varying degree of deviation of the regression lines from the hypothetical one-to-one line. Because these instruments were widely dispersed across the United States, no attempt was made to improve on their calibration. The calibration can easily be corrected by adjusting the gain of the electronic signal. The more important aspect is to demonstrate that the response is linear with mass concentration. This was done by testing the significance (at the 5-percent level) of the correlation coefficients. The significance tests showed that mass concentration determinations made by the light-scattering system are linearly related to gravimetrically determined concentrations.

Comparison of the standard errors of estimate for the various regression lines showed that the variability about the regression lines ranged from 0.9 to 2.46 mg/m^3, the latter value being significantly higher than that obtained with the other five instruments.

As noted earlier, there are a number of factors that could contribute to the scatter of the data. Among these are variable environmental factors such as the composition and size distribution of the aerosol and possible operational difficulties such as leakage around the filter and contamination of the filter during handling. An effort to determine whether the scatter was due to environmental effects was made using selected samples. Filters from pairs of measurements from the same mine which showed substantial differences in the relative response of the light-scattering system to the gravimetric concentration were analyzed and the results compared to the analysis of filters whose gravimetric

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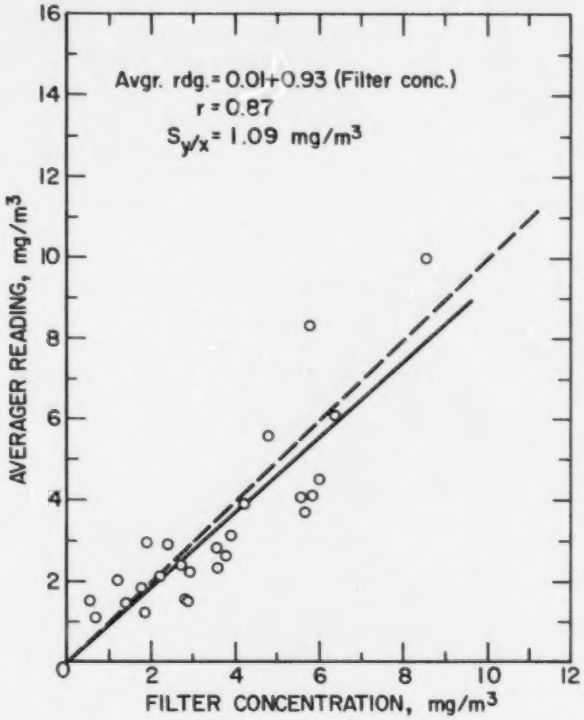

FIGURE 5. - Comparison of respirable dust concentrations found with the light-scattering system to those found from filter weights–SIMSLIN No. 133–District 8.

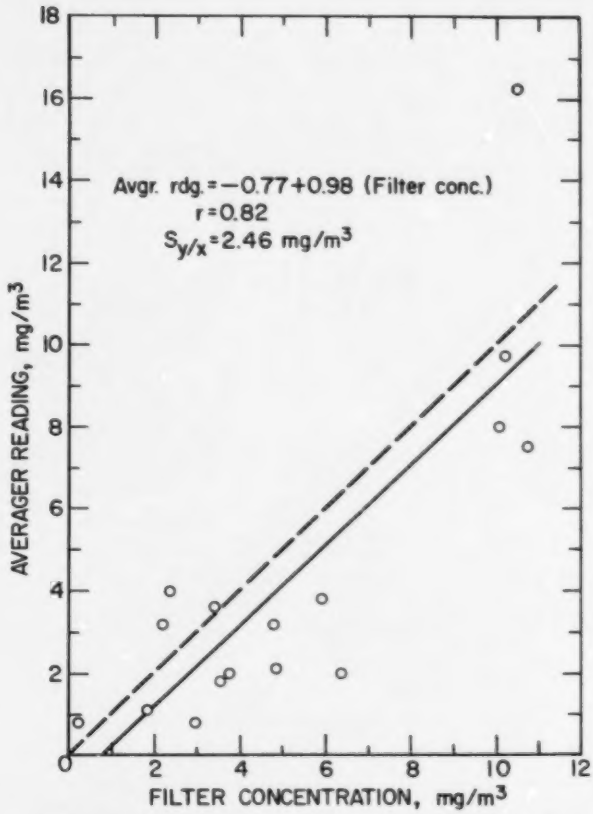

FIGURE 6. - Comparison of respirable dust concentrations found with the light-scattering system to those found from filter weights–SIMSLIN No. 135–District 4.

determination compared favorably with that of the light-scattering system. The dusts on the filters were particle-sized using a Coulter counter.[11] The data were expressed in the following form:

$$\text{Number in range} = K \exp. (-\beta d_{ae}) \quad [12]$$

where d_{ae} is the equivalent aerodynamic diameter of the particle, β a parameter which is a function of the particle size distribution of the aerosol and K a proportionality constant.

Figure 10 shows a comparison of the ratio of concentrations found by the light-scattering system and the filter weight to the value of β. The lack of any apparent relationship suggests that the scatter is not due in large part to differences in size distribution of the dusts sampled. The filter dusts were quantitatively analyzed for percent free silica and calcium carbonate using infrared spectroscopy. Although there were significant quantities of free silica and calcium carbonate contained in some of the samples analyzed, there was no measurable effect on the response of the light-scattering system.

Inspection personnel observed instantaneous readings greater than 100 mg/m³ on 22 different shifts, and three times

[11] Tomb, T. F., and L. D. Raymond. Evaluation of the Penetration Characteristics of a Horizontal Plate Elutriator and of a 10-mm Nylon Cyclone Elutriator. BuMines RI 7367, 1970, 9 pp.

[12] Wynn, A. H. A., and J. G. Dawes. Size Classification of Airborne Dusts in Mines. Safety in Mines Research Establishment, Research Report No. 28, H.M. 50, London, England, 1951, 46 pp.

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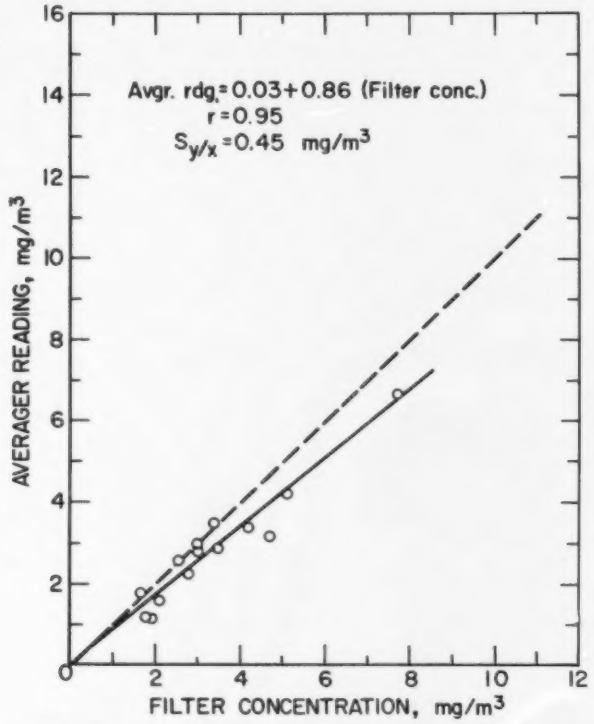

FIGURE 7. - Comparison of respirable dust concentrations found with the light-scattering system to those found from filter weights–SIMSLIN-based MMRDM–Westland No. 2 Mine.

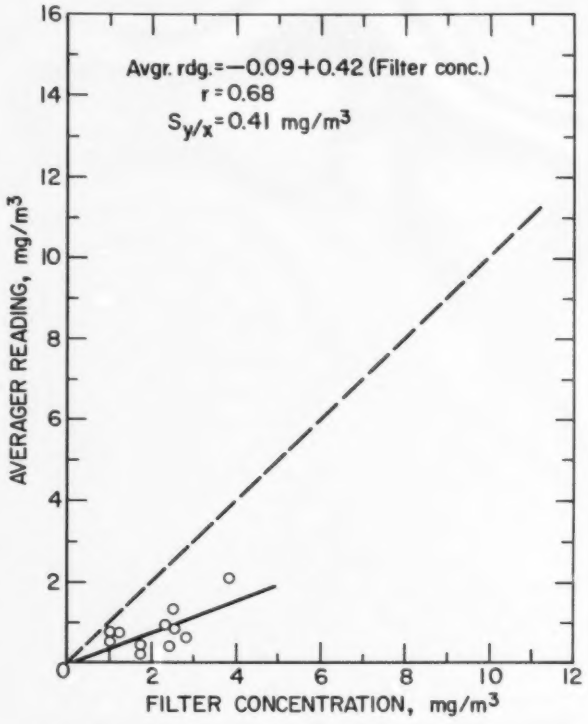

FIGURE 8. - Comparison of respirable dust concentrations found with the light-scattering system to those found from filter weights–SIMSLIN-based MMRDM–Humphrey No. 7 Mine.

saw readings greater than 200 mg/m³. A number of high readings were also observed during the tests of the MMRDM. The number of high readings observed suggest that SIMSLIN II should preferably be used on the 0- to 200-mg/m³ range for measurements near the face and that any instantaneous-reading instrument which may be used in a high-dust environment should have at least as great a range.

The data collected during tests with the MMRDM show much less scatter than the data collected in different mines by inspection personnel. The standard error of estimate obtained from the MMRDM tests ranged from 0.17 to 0.45 mg/m³. Variability of this magnitude is comparable to that obtained under laboratory conditions. A comparison of the computed regression lines and the one-to-one hypothetical line also shows that initial calibration of the instrument is critical and that it will probably have to be done using field measurements in the mine where it will be used.

The ruggedness of SIMSLIN II was demonstrated by its survival of considerable shaking while mounted on a mining machine. However, several of the instruments suffered electronic failure due to a malfunctioning crystal oscillator. Based on testing of the unit in the United Kingdom, only two of 50 SIMSLIN II's reportedly had a similar problem, so its likelihood of occurrence is uncertain.

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SUMMARY

Measurements obtained with the SIMSLIN II respirable dust monitor in several underground coal mines show that respirable mass concentrations determined using its light-scattering system are linearly related to respirable mass concentrations determined gravimetrically; and that the response of the instrument can be adjusted to provide a measure of the respirable mass concentration of dust in the environment. The variability associated with the light-scattering measurements was significantly greater than that typically associated with measurements obtained with personal dust sampling equipment. This was mainly attributed to uncontrolled aerosol variables such as composition and size distribution because tests with the instrument as part of a machine-mounted respirable dust monitor showed the variability to be less than the variability associated with underground measurements obtained using personal sampling equipment.[13]

This study also demonstrated that the optical and electronic systems of the SIMSLIN II instrument are rugged enough for mounting on underground mining equipment.

[13]Tomb, T. F., et al. Comparison of Respirable Dust Concentrations Measured With MRE and Modified Personal Gravimetric Sampling Equipment. BuMines RI 7772, 1973, 29 pp.

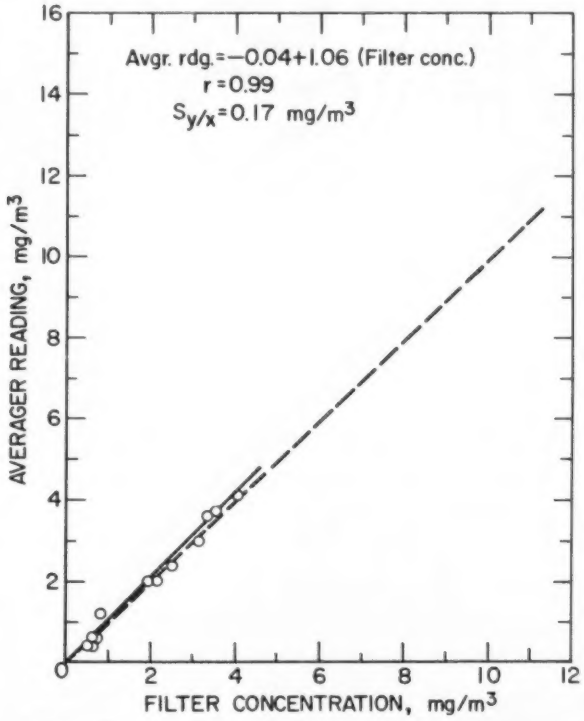

FIGURE 9. - Comparison of respirable dust concentrations found with the light-scattering system to those found from filter weights–SIMSLIN-based MMRDM–Bethlehem No. 78 Mine.

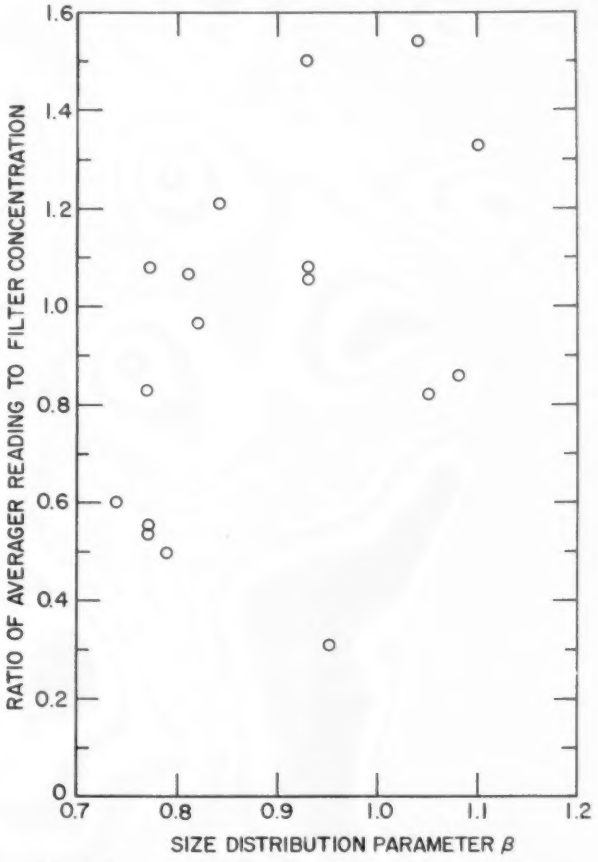

FIGURE 10. - Comparison of relative concentration found with the light-scattering system to particle size distribution.

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